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RESULTS OF A FOUR-YEAR *IN SITU* BIOVENTING DEMONSTRATION

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ABSTRACT

During early February of 1990, a ruptured pipe at a Burlington Northern Railroad (BNRR) fueling pumphouse in Alliance, Nebraska resulted in over 60,000 gallons of No. 2 diesel fuel spilling onto the surrounding soil. Several months later, a subsurface investigation indicated that soils were contaminated to a depth of over 65 feet below ground surface (bgs) and were in a position to impact groundwater, which was observed approximately 70 feet bgs. State regulatory agencies requested that BNRR develop and implement a remedial action plan to treat these diesel-contaminated soils and protect local groundwater. Parsons Engineering Science, Inc. (Parsons ES) was retained for this work and, after evaluating a variety of remediation technologies, recommended using soil bioventing methods to begin the removal of volatile benzene, toluene, ethylbenzene, and xylenes (BTEX) compounds and the long-term biodegradation of all fuel residuals.

Parsons ES first designed and implemented a bioventing pilot test to determine soil properties such as air permeability, and to assess the potential for both volatilization and long-term biodegradation of diesel fuel residuals at the site. Pilot test results confirmed that bioventing was feasible for the remediation of this site, and a full-scale bioventing system was installed on the site in September 1991. This system has operated continuously for over 4 years. BNRR personnel have been responsible for weekly system checks, and Parsons ES has been responsible for semi-annual respiration testing and for soil sampling to determine the level of cleanup achieved during the first 4 years of *in situ* bioventing. This document summarizes the work completed to date and the 4-year findings of this innovative technology demonstration.

1.0 SITE DESCRIPTION

The site is located south of a diesel fuel pumphouse, where the pipe rupture occurred (Figure 1). An estimated 15,000 cubic yards of soil has been contaminated to a depth of approximately 70 feet bgs. In preparation for the pilot test, a single 4-inch-diameter vent well (VW) and six 2-inch-diameter vapor monitoring points (VMPs) were installed on the

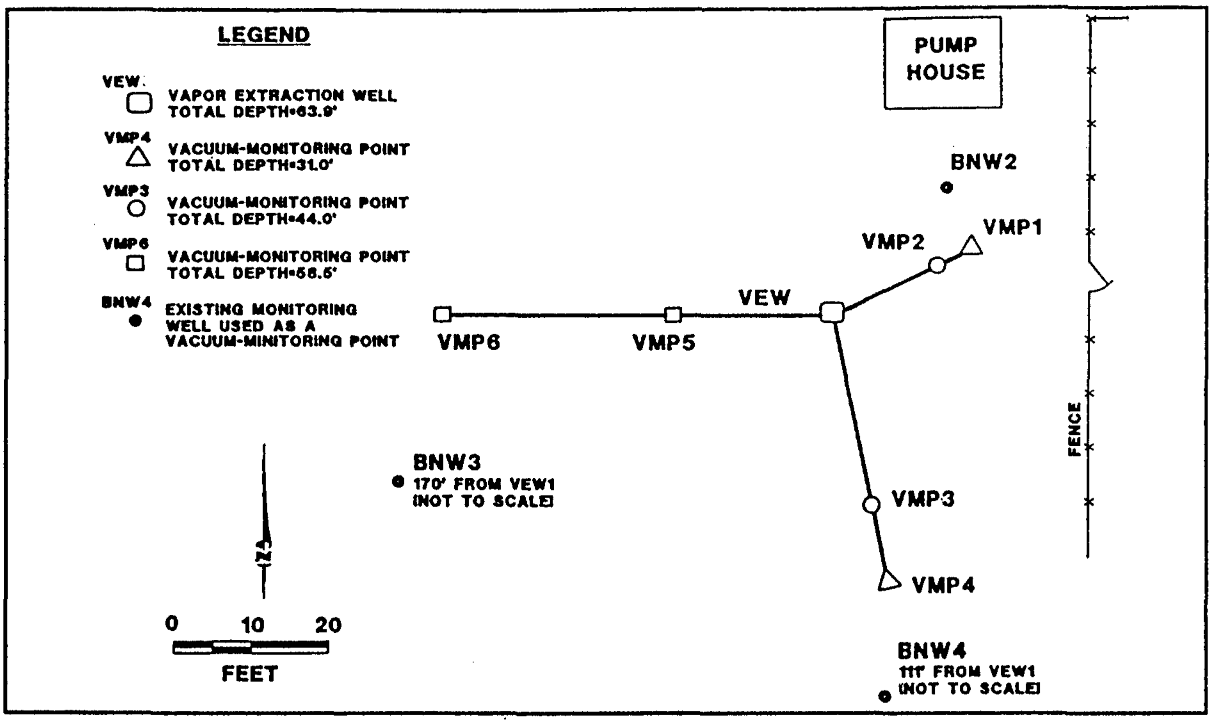


Figure 1. Site plan and monitoring point locations.

site. The Bioventing Pilot Test Results Report prepared for BNRR in June of 1991 presents the results of the pilot test and a more detailed description of the methods used to conduct the test.

1.1 Groundwater Conditions

Groundwater was observed at depths of 68 to 70 feet bgs. Dilute levels of BTEX compounds have been detected in groundwater beneath the site; however, only benzene and total petroleum hydrocarbon (TPH) concentrations exceed their respective cleanup levels of 5 micrograms per liter (ug/L) and 2 milligrams per liter (mg/L), respectively. Due to the thick column of soil above the water table, the vast majority of the diesel fuel spill is adsorbed and occluded in these unsaturated soils. Without soil treatment, soluble BTEX compounds could continue to percolate downward toward the groundwater, creating a larger and more concentrated plume of hydrocarbon contamination.

1.2 Soil Conditions

Soils at this site were characterized during the construction of the VMPs and the VW in April 1991. The general lithology in this area, shown in Figure 2, consists of fine- to medium-grained silty sands from the ground surface to approximately 30 to 35 feet bgs (upper sand zone), interbedded sand and silt/clay lenses that extend from 35 to 50 feet bgs (interbedded zone) and another layer of fine- to medium-grained silty sand that extends to

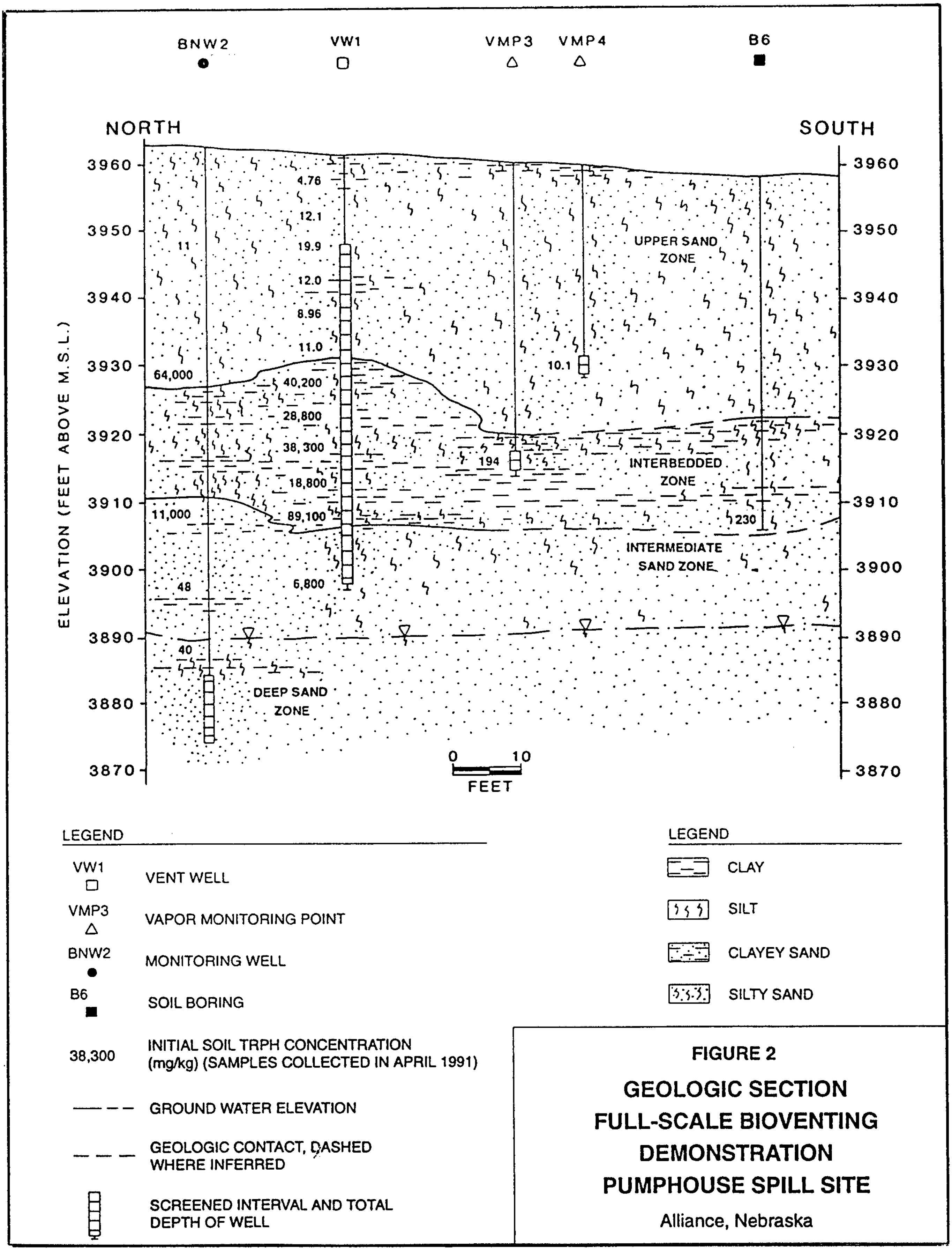


FIGURE 2

GEOLOGIC SECTION FULL-SCALE BIOVENTING DEMONSTRATION PUMPHOUSE SPILL SITE

Alliance, Nebraska

a depth of 70 to 75 feet bgs (intermediate sand zone). Soil moisture varied from 2 percent in the intermediate sand to 11 percent in the interbedded silts and clays.

Soil gas permeability was quantified through vacuum response tests conducted as part of the pilot test in April 1991. Vacuum response and oxygen concentrations were measured at the VMPs and nearby groundwater monitoring wells (Figure 1) while soil gas was being extracted from the VW using a 10-horsepower (hp) vacuum blower. The soil responded rapidly to the vapor extraction system, with measurable vacuum response and increases in oxygen concentrations occurring in all soil zones, including the interbedded silt/clay zone. Using test methods developed by Paul Johnson and others, the average soil gas permeability was estimated at 5 darcys. Because the contaminated soil zone was entirely oxygenated using only the pilot-scale VW, no additional VWs were required for full-scale coverage.

1.3 Initial Soil Contamination and Nutrient Availability

The diesel fuel contamination in the soil appears to be localized within a 60-foot radius of the pumphouse. Initial total recoverable petroleum hydrocarbon (TRPH) concentrations are plotted on the geologic section shown in Figure 2. Based on initial soil analysis and observations made during drilling, it appeared that diesel fuel migrated rapidly downward at the spill site until it encountered the interbedded sand and silt/clay zone at approximately 30 to 35 feet. At this depth, the fuel spread laterally and continued its downward movement through more permeable sand lenses in the interbedded layer.

Initial soil samples collected from the screened intervals of VMP4 and VMP5 were analyzed for ammonia- and nitrate-nitrogen, total Kjeldahl nitrogen (TKN), and water-soluble phosphates. These analyses were performed to determine the concentrations of naturally occurring nutrients available in the soils. Ammonia-nitrogen was found at concentrations of 204 parts per million (ppm) in the upper sand zone (VMP4) and 4.2 ppm in the intermediate sand zone (VMP5), while nitrate-nitrogen levels ranged from 4 ppm in the upper sands to 11 ppm in the intermediate sand zone. TKN levels were found to be 4 ppm in both sand zones. Water-soluble phosphate concentrations ranged from 177 ppm in the upper sands to nearly 6,000 ppm in the intermediate sands. The relatively low nitrogen concentrations found in these soils may be limiting biodegradation rates. To determine if nitrogen addition could improve natural biodegradation rates, an ammonium nitrate solution was added to several VMPs after several months of bioventing. The addition of the nutrient solution did not significantly accelerate fuel consumption rates.

2.0 REMEDIAL GOALS

The objective of this remediation project was to reduce the potential impact of soluable diesel components on local groundwater by removing BTEX from the soil. Removal of BTEX compounds was to be achieved through a combination of short-term soil vapor extraction and continuous bioventing. A secondary objective was to remediate this large site without disruption to existing rail lines or the fuel pumphouse where the spill occurred and to obtain regulatory closure for the lowest possible cost.

3.0 FULL-SCALE SYSTEM DESIGN AND OPERATION

Based on the air permeability and oxygen influence observed during the pilot test, an extraction rate of 100 standard cubic feet per minute (scfm) was selected for full-scale bioventing operations. A 7-horsepower regenerative blower system capable of producing this design flow rate was installed at the site, plumbed to the existing VW, started up, and optimized in September 1991. Soil gas extraction was selected over air injection due to the immediate need to remove volatile and soluble BTEX compounds from the soil before further groundwater contamination occurred. In December 1994, the system was switched to an injection mode and the flow rate was decreased to 60 scfm. This modification was made because much of the soluble BTEX had already been removed/biodegraded, and because bioventing systems require much less maintenance when they operate in an air injection mode. The six VMPs installed during the pilot test continue to be used to monitor pressure response and to ensure that aerobic conditions are maintained throughout the contaminated soil volume.

The full-scale bioventing system has operated continuously for over four years with minimum maintenance downtime. The monthly electrical cost for the system is estimated at approximately $280.00. BNRR personnel have been responsible for weekly system checks and monthly blower filter changes.

4.0 LONG-TERM PERFORMANCE MONITORING

The fuel-consuming capability of native soil bacteria has been examined during seven *in situ* respiration tests conducted by Parsons ES over the four-year operation period. Emissions of volatile hydrocarbons to the atmosphere have been monitored to ensure regulatory compliance and to estimate the amount of hydrocarbons physically removed from the soil. Three soil sampling events, including the initial sampling event in April 1991, have also been conducted in order to document the removal/biodegradation of petroleum hydrocarbons at the pumphouse spill site.

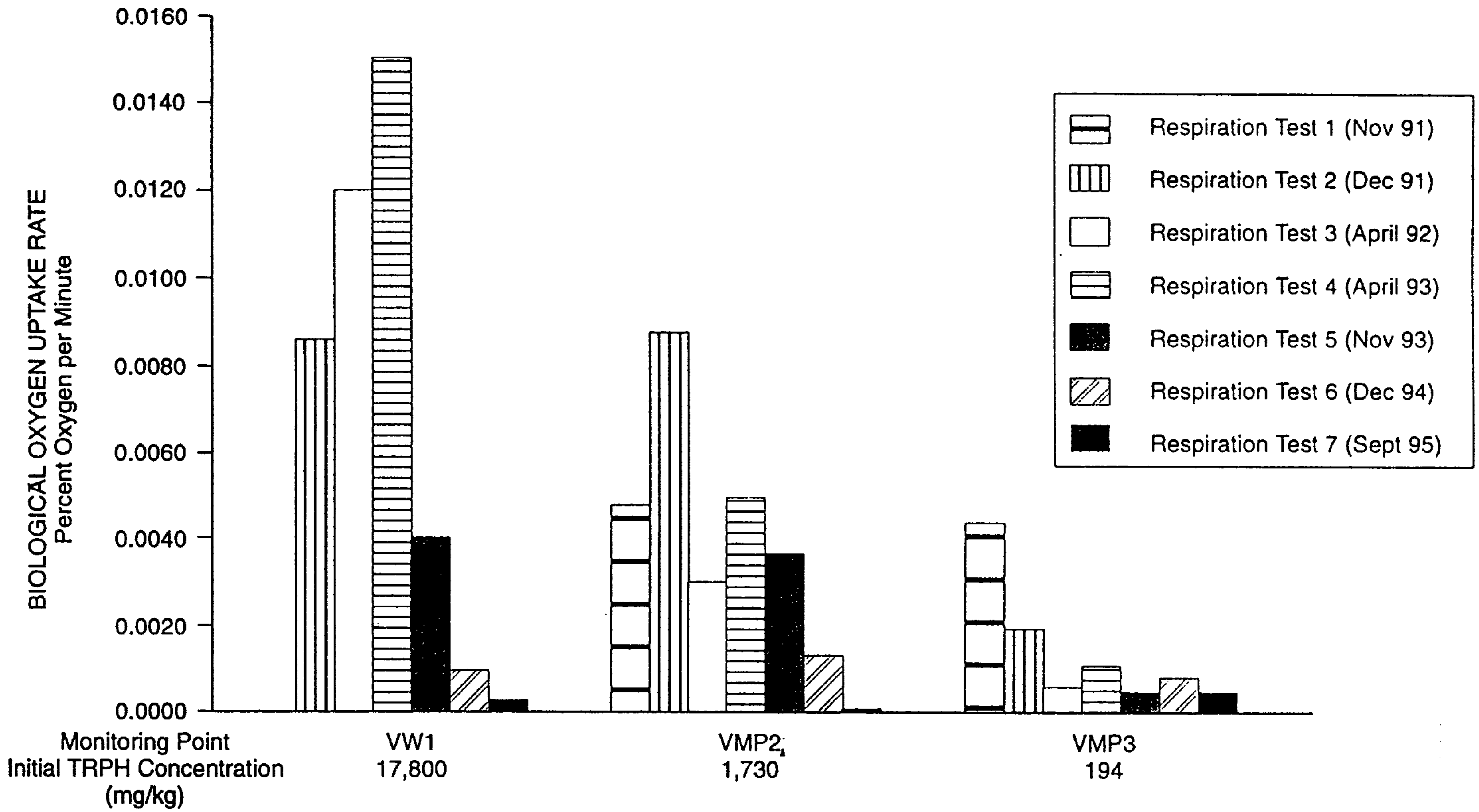
4.1 In Situ Respiration Testing

Continuous air injection into contaminated soil zones provides the necessary oxygen for aerobic biodegradation. When the blower is turned off, oxygen is no longer delivered and soil bacteria consume the available oxygen. Oxygen consumption and carbon dioxide production were monitored at each VMP using a portable O_2/CO_2 gas analyzer. The rate at which soil bacteria consume oxygen is an important indicator of the viability of the fuel-degrading organisms in soils near each VMP. Uncontaminated background VMPs were also monitored during the initial respiration test. Oxygen levels at these background VMPs remained relatively constant at approximately 18 percent, indicating that biological oxygen consumption of natural (nonfuel) organic carbon and abiotic oxygen consumption were not significant in these soils.

The results of respiration tests at the VW and VMPs 2 and 3 are shown in Figure 3. Results indicate that the apparent rates of oxygen utilization have significantly decreased over time. Very low rates of respiration (less than 0.001 percent oxygen uptake per minute) had been measured in VMP3 during the last three tests, indicating that little fuel is now available for biodegradation near this monitoring point. Soil sampling at VMP3 in

FIGURE 3

BIOLOGICAL OXYGEN UPTAKE DURING RESPIRATION TESTS FULL-SCALE BIOVENTING DEMONSTRATION PUMPHOUSE SPILL SITE ALLIANCE, NEBRASKA



September 1995 confirmed that TRPH levels have been reduced from 194 mg/kg to less than 3.3 mg/kg over 4 years of system operation. Respiration rates have also decreased significantly at VW1 and VMP2. Although TRPH concentrations are still somewhat high at fuel-impacted depths at these locations, respiration rates are minimal. Low respiration rates at VW1 and VMP2 indicate that the majority of the readily biodegradable fractions of the diesel fuel have been eliminated. The remaining TRPH in site soils is likely high molecular weight material, with corresponding low water solubilities.

Using a very conservative ratio of 3.5 pounds of oxygen for every 1 pound of hydrocarbon consumed, the fuel biodegradation rate can be estimated for soils immediately surrounding VW1 and each VMP. Using this estimation method, the average biodegradation rate at the center of the spill (near the VW) had been approximately 3,400 mg of TRPH degraded per kg of soil per year during the first two years of system operation (September 1991 to November 1993). During the final respiration testing event in September 1995, the average fuel hydrocarbon consumption rate was estimated to be 130 mg of TRPH degraded per kg of soil per year. This represents an order of magnitude decrease in the rate of fuel consumption, and indicates that the bioventing system has successfully accomplished its objective.

4.2 Volatilization

The removal of volatile and water-soluble compounds such as BTEX from this large diesel fuel spill was also a key objective of this remediation project. Regular sampling of extracted soil gas indicated that approximately 0.3 kg of BTEX and 14.7 kg of diesel vapors have been removed during each day of bioventing operation while the system operated in an extraction mode (September 1991 through December 1994). During this time, an estimated 21,400 kg of total volatile hydrocarbons were removed via extraction by the bioventing system. This mass of hydrocarbon removal could account for approximately 10,000 mg/kg reduction in soil TRPH.

4.3 Soil Sampling Results

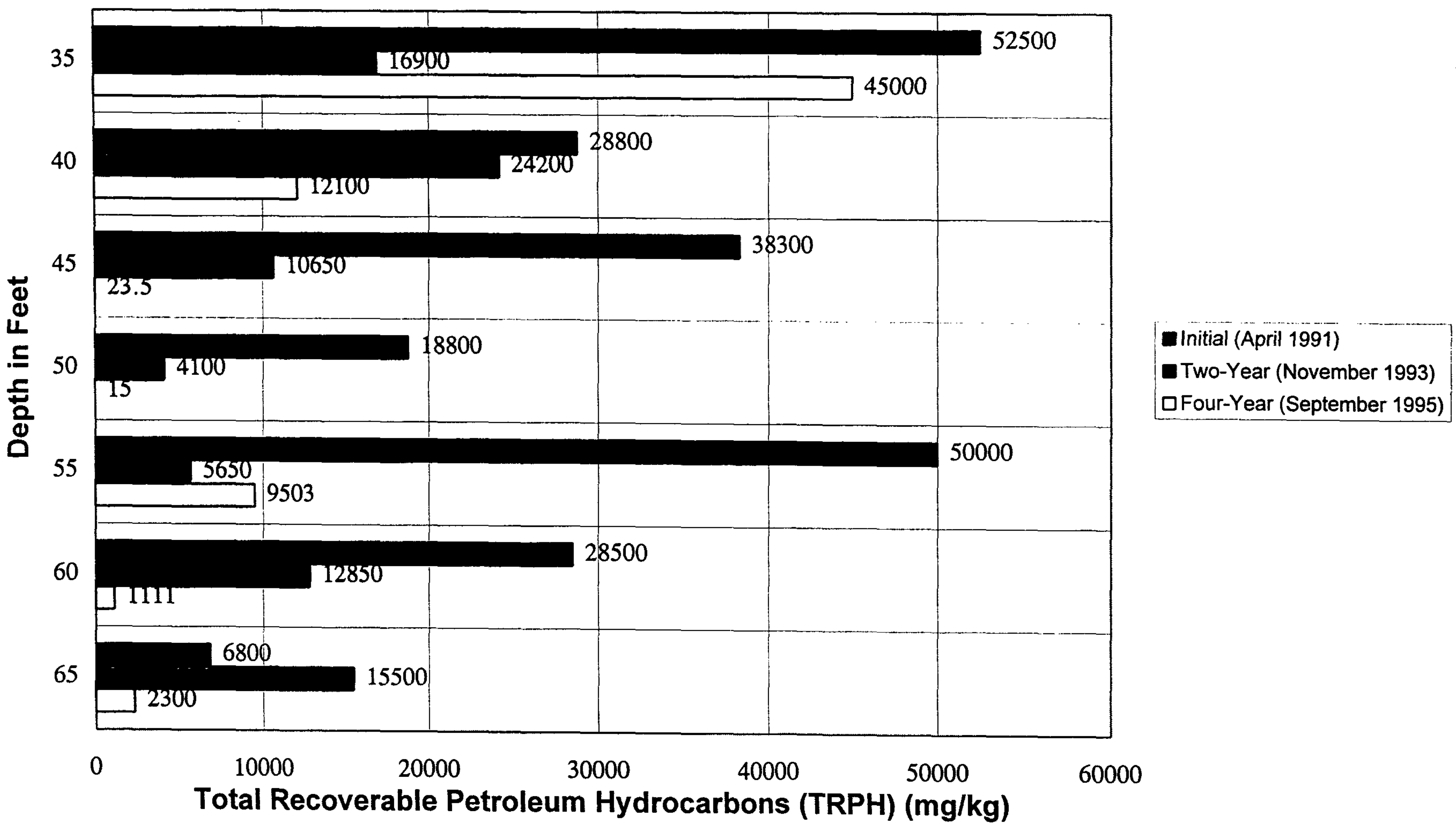
In order to more accurately assess remediation progress, soil sampling programs were conducted in November 1993 and September 1995. In each sampling event, soil samples were collected from a number of boreholes located within a 20-foot radius of VW1. This area was selected for sampling because it represented the most contaminated portion of the site based on initial soil sampling. Sampling depths matched those of the initial site characterization in April 1991. A total of 18 samples was collected from four boreholes in September 1993, and 19 samples were collected from five boreholes in September 1995. All soil samples were analyzed for TRPH by Method 418.1, and six soil samples from each sampling event were also analyzed for BTEX by Method 8020. The samples which were also analyzed for BTEX compounds were chosen based on elevated field hydrocarbon analyzer readings.

Figure 4 illustrates the general reduction in diesel fuel concentrations from initial April 1991 levels. These soil sampling events indicate that an overall TRPH reduction of 75 percent has occurred over the past 4 years of bioventing. Only the 35-foot depth interval showed an apparent increase in fuel concentrations. This apparent increase is likely

FIGURE 4

FOUR-YEAR PETROLEUM HYDROCARBON REDUCTION

Full-Scale Bioventing Demonstration-Pumphouse Spill Site - Alliance, Nebraska



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Note: All two-year samples represent an average of 2 or more sample locations per depth.

caused by the non-uniform distribution of hydrocarbon contamination in the interbedded zone at this depth. Concentrations of fuel contamination are likely to be greater in clay lenses in the zone because of higher capillary retention of liquids, and because oxygen is more difficult to deliver in these soils. The soil sample collected during the September 1995 event could easily have contained a higher percentage of fine-grained soils than the sample collected during the November 1993 event, thereby yielding a higher fuel concentration.

The overall TRPH reduction observed during the first four years of system operation was approximately 75 percent. Fifty-five percent of the TRPH was removed in the first two years of system operation, with an additional 20 percent of the TRPH being removed between November 1993 and September 1995. These results indicate that the rate of TRPH removal is slowing over time, and that the benefits of continued system operation are decreasing over time.

Figure 5 illustrates the reduction in BTEX concentrations achieved during the last two years of system operation (from November 1993 to September 1995), and Table 1 summarizes the results of BTEX analyses for the September 1995 sampling event. Total BTEX concentrations have been reduced substantially at all depths, and BTEX concentrations overall have been reduced 75 percent between November 1993 and September 1995.

It is estimated that approximately 9,500 pounds of BTEX were spilled at the Alliance site in 1990. In November 1993, an estimated 1,630 pounds of BTEX remained in contaminated soil zones. As of September 1995, only 380 pounds of BTEX are estimated to be present in site soils. This remaining BTEX represents only 4 percent of the 9,500 pounds of BTEX initially released. Because 96 percent of the risk-driving BTEX compounds have been removed/biodegraded, the health risk at this site has been substantially reduced.

5.0 CONCLUSIONS

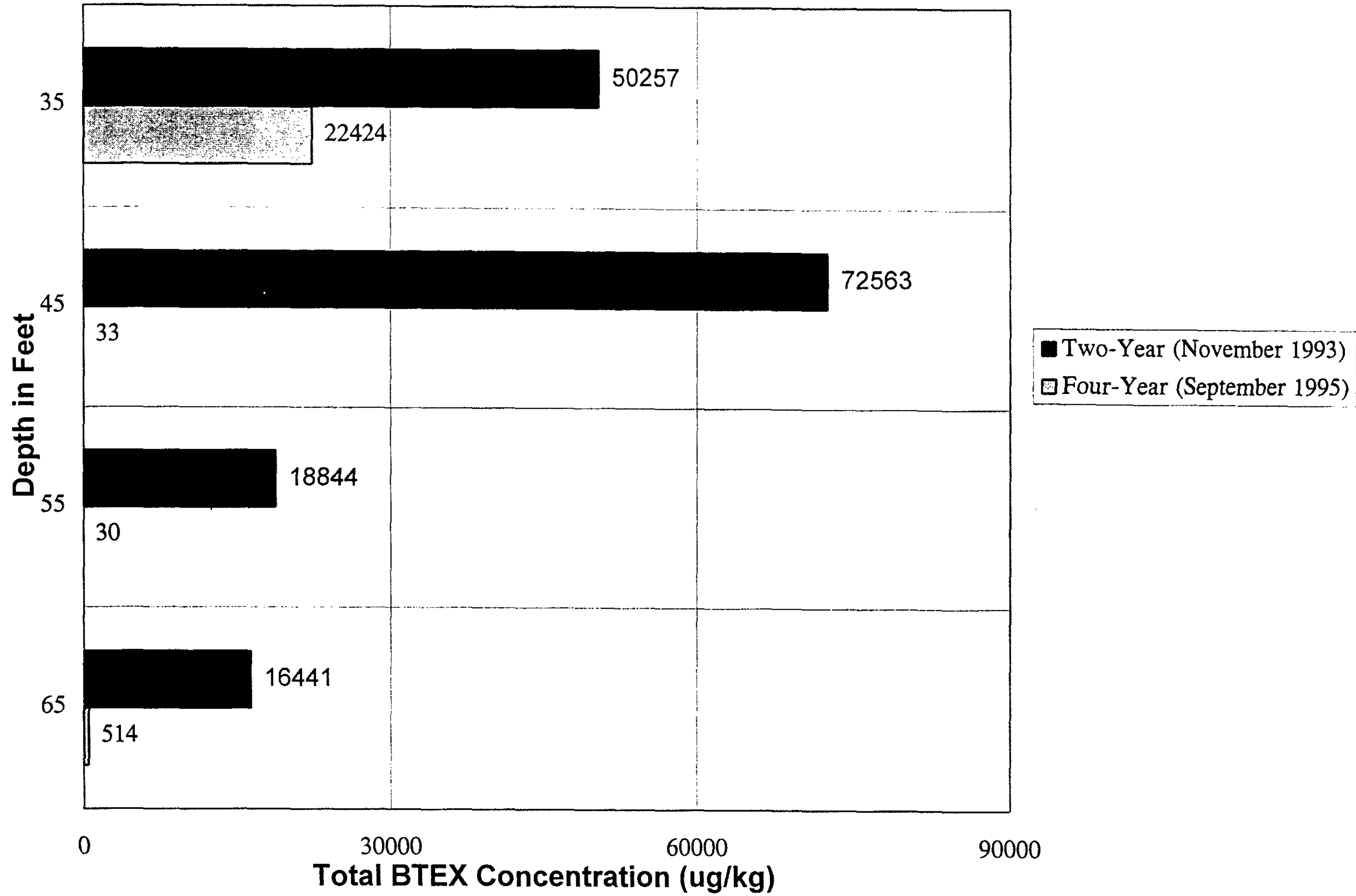
Full-scale bioventing at this large diesel spill site has produced encouraging results during the first 4 years of operation. Remediation is taking place throughout a 70-foot soil profile with no disruption to railroad operations or facilities. Specific indicators of progress include:

- Recent soil sampling results which indicated that a 75-percent decrease in TRPH concentrations has occurred in the most contaminated portion of the site during the 4-year demonstration. A 75 percent reduction in soil BTEX concentrations has also occurred in the last two years of system operation (between November 1993 and September 1995). The low levels of remaining BTEX should pose little or no risk to the local groundwater or to workers during any potential soil excavations at the site.
- Significant decreases in respiration rates across the site. These reductions in respiration rates indicate a significant reduction in the concentration of readily biodegradable, low- to medium-molecular weight petroleum hydrocarbons in fuel-impacted soils.

FIGURE 5

TOTAL BTEX REDUCTION IN THE LAST TWO YEARS OF SYSTEM OPERATION

Full-Scale Bioventing Demonstration - Pumphouse Spill Site - Alliance, Nebraska



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Note: Number of samples indicated in parentheses.

TABLE 1

CONCENTRATIONS OF BENZENE, TOLUENE, ETHYLBENZENE, AND XYLENES IN SOIL SAMPLES TAKEN WITHIN 20 FEET OF THE VENT WELL
SEPTEMBER 1995

		Concentrations in µg / kg			
Sample I.D.	Depth (ft)	Benzene	Toluene	Ethylbenzene	Xylenes
BN-AL-SB8-65	65	ND	ND	ND	ND
BN-AL-SB8-35	35	140 J	300 J	550 J	27000
BN-AL-SB7-65	65	ND	ND	2.3 J	4.8 J
BN-AL-SB7-55	55	6.3 J	2.8 J	ND	ND
BN-AL-SB7-45	45	2.6 J	ND	ND	ND
BN-AL-SB7-35	35	88 J	270 J	1500	15000

J - Detected but value is estimated because it is below the practical quantitation limit.
ND - Not detected.

5.1 Summary of Costs to Date

The total cost to date of bioventing at this site including pilot testing, full-scale installation, and 4 years of operation and maintenance is approximately $146,000. Figure 6 shows a breakdown of total cost and a cost per cubic yard based on an estimated contaminated soil volume of 15,000 cubic yards. These costs include all Parsons ES project administration and reporting costs, but do not include electrical costs or BNRR labor costs for system checks. Parsons ES has completed this technology demonstration on time and within budget.

5.2 Site Closure

Because the majority of the volatile and water-soluble contaminants (i.e. BTEX compounds) have been volatilized and biodegraded, and because the high-molecular-weight compounds remaining in the soil are not expected to cause further deterioration of groundwater quality, Parsons ES recommended pursuing a risk-based closure of vadose zone soils at the pumphouse spill site. Early in 1996, the State of Nebraska reviewed soil data from the site and concurred that the site could be closed based on the significant risk reduction which had been achieved.

ACKNOWLEDGEMENTS

Parsons ES would like to thank Burlington Northern Railroad for their sponsorship of the full-scale bioventing demonstration and BNRR employees Mr. Joe Ringbauer and Mr. Pat Sherlock for there assistance in operating the system.

FIGURE 6
COST SUMMARY FOR
Full-Scale Bioventing Demonstration - Pumphouse Spill Site - Alliance, Nebraska